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Optimization method for stamping tools under reliability constraints using genetic algorithms and finite element simulations

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ABSTRACT

Controlling variability and process optimization are major issues of manufacturing processes which should be tackled together since optimal processes must be robust. There is a lack of numerical tool combining optimization and robustness. In this paper, a complete approach starting from modelling and leading to the selection of robust optimal process parameters is proposed. A model of stamping part is developed through Finite Element simulation codes and validated by experimental methods. The search for optimal tool configurations is performed by optimizing a desirability function and by means of a genetic algorithm based optimization code. Several tool configurations are selected from the resulting solutions and are observed through robustness analysis. Noise parameters relating to friction and material mechanical properties are taken into consideration during this analysis. A quadratic response surface developed with design of experiments (DOE) links noise parameters to geometrical variations of parts. For every optimal configuration, the rate of non-conform parts which do not satisfy the design requirements is assessed and the more robust tool configuration is selected. Finally, a sensitivity analysis is performed on this ultimate configuration to observe the respective influence of noise parameters on the process scattering. The method has been applied on a U-shape part.

1. Introduction

In manufacturing process design, the objective is to find a production process which leads to produce parts as close as possible to the nominal values. This approach is commonly called the optimization process. Moreover, during production, various sources of variability may arise like temperature or material variations. These variations often lead to very significant changes in production and non-conform part. The major challenge is therefore to design a manufacturing process robust to these changes.

In this paper, it is proposed a general approach applied to a deep drawing operation to find different optimal configurations and then to quantify their robustness. A selection of the best robust configuration is then possible.

The deep drawing process consists in transforming flat sheet blanks into cups, boxes or particular profiles corresponding to non-developable shapes. These stamped parts are typically employed in automotive or aeronautic industries.

Stamping process is mainly used for the production of large series of parts because the design and setup of the tool are difficult and time consuming. In press shop, one of the most important problems is to obtain formed parts with precise geometric characteristics corresponding to the specifications of the customers. During the past 20 years, many works have been focused on the subject, and lead to investigate different methodologies, which have improved stamping tool technologies according to a better satisfaction of geometric requirements. These methods are essentially based on numerical simulations (i.e. finite element) of the stress inside of sheet blanks coupled to the development of optimization strategies.

Optimization strategies mainly aim at avoiding and limiting part defects through the stamping process. Many different approaches have been developed. Direct optimization is used to find effective configurations of the tools. It requires a great number of time-consuming simulations and does not converge on the global optimum of the tool configurations. Other approaches are based on the computation of local response surfaces and on the global optimization of the tool setup. Response surfaces are regarded as fast and accurate simulation tools involved in the numerical process of a global optimization method; they are often computed using design of experiment techniques.

In the industry, dominant defects are springback and excessive localized strains that lead to wrinkling or tearing the parts. These main defects are directly influenced by the parameters of the stamping process and are usually corrected by improving the tool setups. During the production process, even if the stamping process

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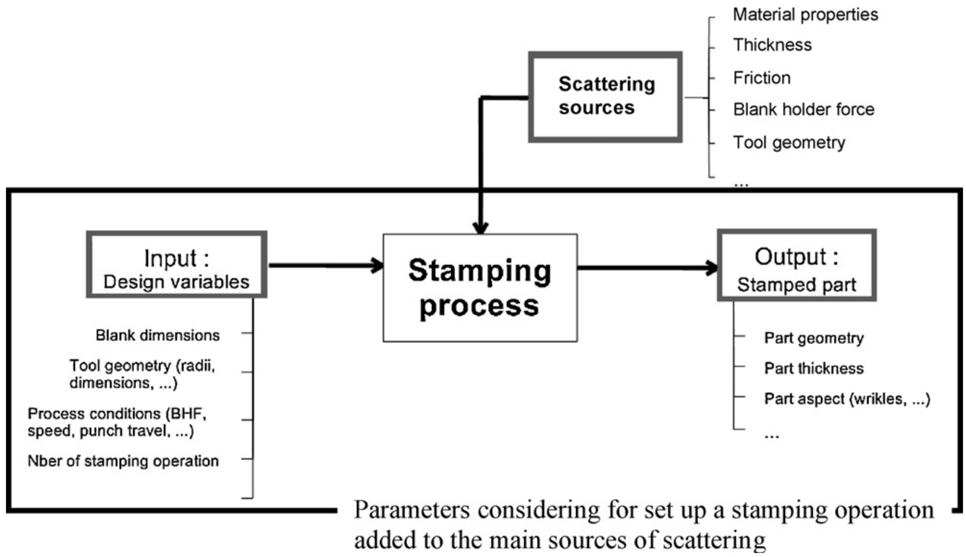

Fig. 1. Stamping process, input, output and main scattering sources.

has been optimally designed, parts may have significant dimensional scatter. This variability in the characteristics of the product is mainly due to some scattered input process parameters (force, blank dimension, friction conditions, material scattering, etc.). Fig. 1 shows a schematic representation of a stamping process. It displays the main parameters which are classically taken into account for the setup of the operation and the different scattering sources. Most of works concerned with variability in stamping do not take into consideration these sources of scattering.

Some authors have recently investigated the effects of the coupling between the sources of process variability and the requirement quality of parts. De Souza and Rolfe (2008) have developed an analytical model of bending part and quantified its variability in function of process scatter. Col (2003) has studied few forming process scatters and attended to identify their origins. Gantar and Kuzman (2002) have evaluated the process stability in spite of different sources of scatter. It is proposed an evolution of its work in Gantar and Kuzman (2005) by coupling a procedure of optimization to the previous stability analysis.

These authors highlight the main influent input parameters of the stamping process:

- Materials properties scatter (hardening coefficient, yield strength, friction coefficient, etc.),
- Variation of the blank thickness.

Investigations are proposed by Sigvant and Carleer (2006) to quantify the range of variations of the material characteristics.

All of these recent studies have underlined the significant influence of the process variability on the geometry of the parts, but few papers propose a global approach starting from modelling the behaviour of the parts and the variability sources and leading to process optimization. The objective of our work is to propose such an approach and validate it. Validation is achieved by performing the optimization of a stamping process, which leads to obtain parts conform to the customer specifications and robust to the sources of scattering. This approach is commonly regarded as a reliability method.

Reliability of processes is defined as the capacity of a product to maintain the value of its performances, in spite of the variations in the functioning conditions and the uncertainties relating to the parameters of the process. Taguchi (1993) is considered as the pioneer in robust design; more particularly, in the definition of loss functions and signal-to-noise ratios. According to Taguchi, there are two types of parameters: the parameters controlled by the process and the parameters generating noise (variations). Generally, for complex processes, interactions between these parameters and the controlled parameters are related to uncertainties affecting their target values.

1.1. Modelling reliability

Approaches of reliability modelling aims at finding relations linking the geometric variables of parts to some process characteristics (values and their related variability); see Fig. 2. These relations are usually based on physical analysis leading to complex functions or implicit functions such as finite element simulations. The product variability is computed using integration techniques or stochastic approaches such as Monte Carlo or Quasi-Monte Carlo Simulations (respectively MCS or QMCS) (Niederreiter, 1992).

The computation of the output distributions (i.e. geometrical parameters of the part resulting from the stamping process) depends on the estimated variability of every input parameter (i.e. process parameters and material scattering).

The statistical characterization of the input parameters is difficult to quantify and requires major investigations and feedback on experimental data. The identification of the statistical properties of the input process parameters is based on particular statistical modes (i.e. average, standard deviation, skewness, kurtosis, . . .). Typically, Gaussian distributions are the statistical distribution being used for modelling variability. The average and standard deviations are required for the definition of every input parameter.

1.2. General approach

Regarding the uncertainties in the stamping process, the complexity of the strain path during the stamping operations and the number of process parameters to optimize, the setup of stamping tool is difficult and time-consuming task. The engineers are using their expertise and experience feedback to design stamping tools. Different empirical rules and digital tools (simulations) are supporting designers in their technological choices. Generally, several tool configurations are leading to a geometry respecting the geometrical and structural specifications of the design requirements. However, these configurations are not equivalent since they may